Bi-Directional Reflectance Measurements of the Ocean Bottom

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Award#: N000149910008
http://optics.physics.miami.edu/exp/mainpage.htm

LONG-TERM GOALS

My long-term goals are to experimentally determine the interrelationships and variability of optical properties in the ocean and atmosphere. I have been concentrating on aspects of scattering and reflectance, both inelastic and elastic, and measurements of the radiance distribution in the ocean and atmosphere. These measurements can be combined to test and improve radiative transfer models, which are used to predict image and light transmission in the ocean.

OBJECTIVES

The objectives in this cycle are two fold. The major effort is in support of the MCM experiments. Our efforts for this consist of measuring the Bi-directional Reflectance Distribution Function (BRDF) of the surface around the measurement areas, making measurements of the volume scattering function (VSF) of the water column using the General Angle Scattering Meter (GASM), and making measurements of the Point Spread Function (PSF) in the water using our PSF instrument.

The second effort is more general and is aimed at understanding the BRDF of benthic surfaces and finishing our analysis of CoBOP data.

APPROACH

Starting with the second effort, in our previous work we have built an instrument to measure the in-situ bi-directional reflectance of surfaces at 3 wavelengths (480, 565, and 650 nm were chosen because of the availability of bright LED sources) [described in Voss et al., 2000]. The measurement volume of the instrument is basically a hemisphere with a radius of 10 cm, which is placed on the surface to be measured. The surface is sequentially illuminated at angles ranging from 0-65 degrees (0, 5, 15, 25, 35, 45, 55, 65). The reflected light is measured with fibers at the same zenith angels as the illumination and at 29 azimuthal angles from 0 to 360 degrees. The sample area is approximately 3 cm^2. Light from each viewing direction is collected with fiber optic collectors and then brought into a common "block" array" which is imaged on a camera. In this way all viewing angles are collected at a single time, greatly decreasing sample acquisition time. The instrument is small and compact enough for diver operation in-situ.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **Bi-Directional Reflectance Measurements of the Ocean Bottom**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Physics,University of Miami,,Coral Gables,,FL, 33124**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
My long-term goals are to experimentally determine the interrelationships and variability of optical properties in the ocean and atmosphere. I have been concentrating on aspects of scattering and reflectance, both inelastic and elastic, and measurements of the radiance distribution in the ocean and atmosphere. These measurements can be combined to test and improve radiative transfer models, which are used to predict image and light transmission in the ocean.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

We are using this instrument in conjunction with the ONR sponsored Coastal Benthic Optical Properties (CoBOP) project. Our first task was to reduce the field data acquired in this project and prepare the manuscript describing the data. Our next effort involves measuring the BRDF of various controlled surfaces in the laboratory to give us a basis to look at the important factors controlling the BRDF. The goal is a predictive model of the BRDF for submerged surfaces.

The efforts for our first task focuses on calibrating the instrumentation (BRDF, GASM, PSF) before and after the field tests, acquiring data during the MCM field tests, then reducing this data in a timely fashion. We also needed to modify the data acquisition systems for the GASM and PSF, as they were based previously on outdated (and broken) computers.

WORK COMPLETED

In the second field experiment of the CoBOP project we obtained many measurements of differing sediment types in the coastal area. We have found an analytical fit that characterizes these surfaces and can be used in radiative transfer models to predict the light field near the bottom. The results of this work have been described in a manuscript submitted to the CoBOP special issue of Limnol. and Oceanogr. (Zhang et al. 2001).

We also have acquired and analyzed upwelling radiance distribution data taken in optically shallow water. This work has also been submitted to the CoBOP special issue (Voss et al. 2001).
We have very recently participated in the first MCM field experiment. The data from this experiment is currently being reduced.

RESULTS

Our measurements have shown several common features in the sediments we have measured. The geometric structure of the BRDF appears to be independent of wavelength. In other words, the BRDF for a given sample, when normalized to some factor such as the 0-45 (incident-received) reflectance, commonly measured, is independent of wavelength. This occurs even in the colored sediments we have measured. Thus it appears that we can make our measurements at only one wavelength and have an accurate measure of the BRDF (thus saving a factor of 3 in diver time, or increasing our sampling rate by a factor of 3).

The next common feature is that even simple surfaces, such as sand, exhibit non-Lambertian behavior in two directions. In the specular direction there can be a small enhancement in the reflectance for many natural surfaces. However the largest non-Lambertian feature seems to be in the "hotspot" or backward direction. In almost all the samples we have seen, for an incident illumination polar angle (θ_i)>25˚, there is an enhancement of the reflectance in the hotspot of up to a factor of 3 over the normal direction. For normal illumination the samples appear near Lambertian, however this and the hotspot are functions of the grain size. We have taken our data set and formed analytical models representing the range of samples measured, and grain sizes from 400 – 1000 μm. In the Figures following we show the variation of the model BRDF with sample (or grain size). The first figure shows the BRDF in the principal plane (containing the illumination beam and the surface normal) for normal illumination, the second shows the BRDF for a source at 75 degrees nadir illumination angle.

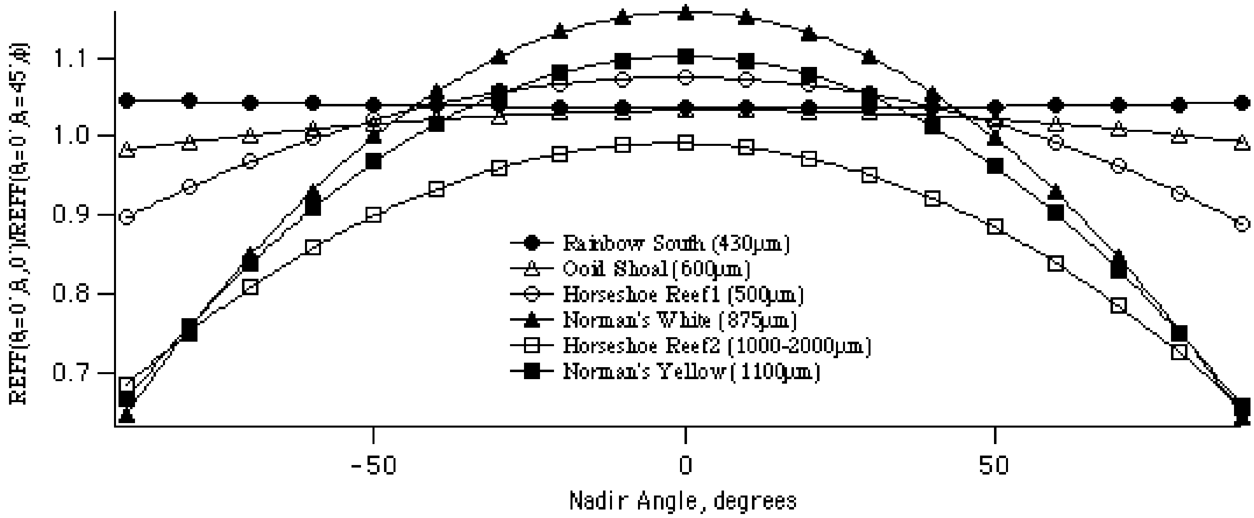

Figure 1) Normalized analytical model of the BRDF for 6 samples. This is for normal illumination and is along the principal plane (plane containing the surface normal and the illumination beam). As can be seen the small grain sizes have a near Lambertian BRDF for this case (which is nearly independent of view angle). As the grain size increases the BRDF decreases towards the sides. In this case, with large grain size samples (1000µm) the BRDF decreases by 30% at 85 degrees.

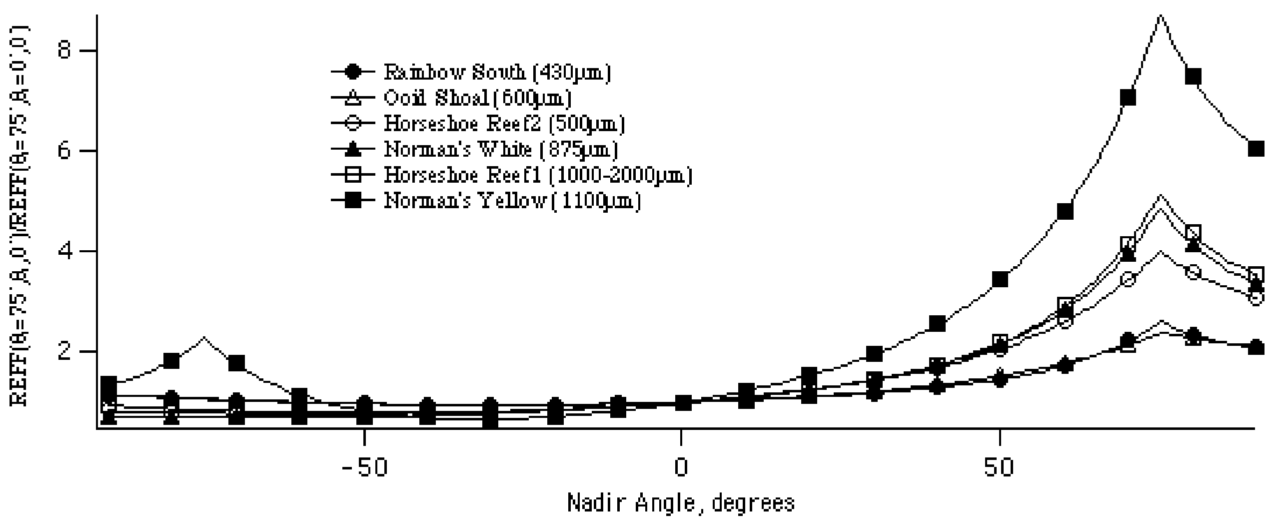

Figure 2 Normalized analytical model of the BRDF for 6 samples. This is for illumination from an angle of 75 degrees and is along the principal plane (plane containing the surface normal and the illumination beam). The illuminating beam is on the right side so the peak on the right side is the back scattering or "hotspot" direction. In this case the largest hotspots are for samples with the largest grain sizes. One sample shows a specular peak (on the left), but in general this is not evident in most rough surfaces.

This example shows our results to date. We will be working with artificial surfaces in the laboratory to test our ability to model the BRDF in the hopes of getting a predictive model of the BRDF.

IMPACT/APPLICATIONS

Knowledge of the BRDF for benthic surfaces will allow more accurate modeling of the light field near the bottom. As this parameter was virtually unknown, all of the results will be an advance in the state of knowledge of this parameter.

TRANSITIONS

We have provided our analytical fit parameters to the modeling component of the CoBOP program for use in their RTE models (Mobley et al, 2001). We are using the instrumentation in a current 6.2 project to help validate and test several navy systems.

RELATED PROJECTS

In our work we have been working closely with many of the CoBOP researchers, but in particular with Drs. Curt Mobley (Sequoia), Pam Reid (Univ. of Miami), Alan Decho (Univ of South Carolina).

REFERENCES

B. Hapke, "Theory of reflectance and emittance spectroscopy, Topics in remote sensing Vol. 3", Cambridge University Press, New York, 1993.

C. D. Mobley, L. Sundman, H. Zhang and K. J. Voss, Effects of Optically Shallow Bottoms on water leaving radiances, Ocean Optics XV, Monte Carlo, October, 2000.

K. J. Voss, A. Chapin, M. Monti, and H. Zhang, An instrument to measure the Bi-directional reflectance distribution function (BRDF) of surfaces, Accepted, Applied Optics, August 2000.

K. J. Voss, C. D. Mobley, L. K. Sundman, J. Ivey, and C. Mazell, The spectral upwelling radiance distribution in optically shallow waters, submitted Limnol. and Oceanogr., September 2001.

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PUBLICATIONS

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K. J. Voss, A. Chapin, M. Monti, and H. Zhang, An instrument to measure the Bi-directional reflectance distribution function (BRDF) of surfaces, 2000, Applied Optics, **39**, 6197 - 6206.

C. Hu and K. J. Voss, “Measurement of solar stimulated fluorescence in natural waters”, 1998, Limnol. and Ocean., **43**: 1198 - 1206.

K J. Voss, W. M. Balch, K. A. Kilpatrick, "Scattering and attenuation properties of <u>Emiliania</u> <u>huxleyi</u> cells and their detached coccoliths", 1998, Limnol. and Ocean., **43**: 870-876.

J. S. Bartlett, K. J. Voss, S. Sathyendranath, and A. Vodacek, “ Raman scattering by pure water and seawater”, 1998, Applied Optics, **37**: 3324 - 3332.

C. Hu and K. J. Voss, "*In situ* measurement of Raman scattering in clear ocean water”, 1997, Applied Optics, **36**: 6962 - 6967.

B. J. Frew and K. J. Voss, “Measurement of the Point Spread Function in a layered system”, 1997, Applied Optics, **36**: 3335-3337.

Y. Liu and K. J. Voss, “Polarized radiance distribution measurements of skylight: II. experiment and data”, 1997, Applied Optics, **36**: 8753 - 8764.

K. J. Voss and Y. Liu, “Polarized radiance distribution measurements of skylight: I. system description and characterization”, 1997, Applied Optics, **36** :6083-6094.